Soil Physical Quality of Reclaimed Mine Soil Using FGD Products

M. K. Shukla[1], R. Lal[1], and M. H. Ebinger[2]

[1]School of Natural Resources, FAES, The Ohio State University [2]Los Alamos National Laboratory, New Mexico

ABSTRACT

Soil physical properties were assessed and compared for reclaimed mine soils (RMS), undisturbed soils (UMS) and mine spoils (SP) in Tuscarawas County ($40^0$33'N and $81^0$31'W) of southeastern Ohio. Prior to reclamation the study area consisted of 10 ha of exposed, extremely acidic, and highly erodible underclay. The soil of RMS site was of Bethesda soil series (loamy-skeletal, mixed, active, acid, mesic Typic Udorthents). Three treatments applied to the RMS plots in 1994 were: (1) Flue gas desulfurization (FGD) wastes (280 Mgha^{-1}); (2) FGD + compost (FGDC, 280 Mgha^{-1} + 112 Mgha^{-1}); and (3) soil +limestone (SL, at a rate 20 cm borrowed soil + 45 Mgha^{-1} L and graded spoil + 112 Mgha^{-1} L). Each treatment was replicated twice, six core and bulk soil samples were obtained from each treatment for the 0 to 10 cm depth in June 2002. Additional bulk soil samples were obtained for the 10 to 20 cm depth. Soil properties measured were: bulk density (ρ_b), water stable aggregation (WSA), mean weight diameter (MWD), effective porosity (f_e), available water capacity (AWC), saturated hydraulic conductivity (K_s), total infiltration (I), infiltration at 5 min (i_5) and 2.5 h (i_c), soil organic carbon (SOC) concentration and pool, pH and electrical conductivity (EC). For the o to 10 cm depth, the ρ_b was smaller for the FGDC and FGD than other treatments. The SOC varied in the order UMS> SL > FGDC> FGD> SP. The WSA was higher for UMS and SL than other treatments and the MWD varied in the order SL > UMS ~ FGDC ~ FGD > SP. The K_s was smaller for the SP than UMS and FGDC treatments. Soil pH showed that SP was very acidic (pH ~ 3.4) but other treatments ranged fom weak acid to weak base (pH 6.6-7.5). The EC was the lowest for the SP and FGDC (0.03 dS m^{-1}). The I was highest for the UMS (52.88 cm) and lowest for the SP (6.42 cm). The WSA, ρ_b, MWD, SOC and i_5 were higher for SL than FGD and FGDC treatment. However, i_c, I, Ks, AWC and f_e were higher for FGDC than FGD and SL. The higher WSA, SOC, I, K_s, and lower EC and pH for RMS than SP are indicative of the effectiveness of FGD based reclamation procedure.

INTRODUCTION

Mining causes drastic perturbations in properties and processes of soil profile. The sudden perturbation gives little time for soil's inherent resilience to respond, leading to soil degradation and decline in soil quality (Lal 1997). Mining alters soil physical and structural properties, loss of soil organic carbon (SOC) (Akala and Lal, 2001), increase in bulk density (ρ_b), and reduction in total porosity (f_t) (Chong et al., 1986). The material handling operations for restoration (e.g., land forming, spreading topsoil, mulching etc) exacerbate soil compaction and alter physical and structural characteristics and restrict root development (Jansen, 1981).

The total land area of Ohio is approximately 7.6 Mha, of which nearly 35% is agricultural land (Frey, 1973) and 0.29 to 0.32 Mha is mined soil (AMLSF, 2000). Restoration of disturbed mined soil can improve soil quality, biomass productivity and SOC concentration. The process of mined soil reclamation involves: (1) application of topsoil (about 30 cm depth) either from the same location or brought in from elsewhere, (2) use of alkaline Flue Gas Desulfurization (FGD) by- products, (3) use of organic amendments such as compost or sludge, and (4) application of chemical fertilizers (N-P-K) (Dick et al., 1998).

The reclamation involving complete regrading of spoil material and imported topsoil placement can be expensive. Therefore, use of FGD by-products can be a useful alternative. These by-products are not being used effectively and only 34% of fly ash, 31% of bottom ashes, 80% of boiler slags and 10% of FGD are used for mined soil reclamation (ACAA, 1998). The FGD products applied with stabilizing materials (e.g. fly ash, limestone, and alkalizing agents) can mitigate soil acidity and sodicity, decrease solubility of soil P, increase soil nutrient status, enhance water infiltration and improve soil quality while decreasing cost of disposal of these products (Dick et al., 1998). The FGD products are variable due to variety of techniques and extractants used in their production, and trace element concentration can vary depending upon amount of fly ash used.

OBJECTIVES AND HYPOTHESIS

This study was designed to assess changes in soil mechanical, hydrological and chemical properties of a reclaimed mined soil using FGD by-products in relation to the undisturbed (unmined) soil. The main hypothesis for the study was that "the reclamation improves soil structure, which can be inferred from the higher cumulative water infiltration (I), available water capacity (AWC), effective porosity (f_e) and SOC concentration as compared to an unreclaimed mined soil or spoil (SP)". The secondary hypothesis was that "mined soils reclaimed with FGD-byproducts have less surface crusting and compaction, and more water infiltration rate and water holding capacity than those without FGD product". The specific objectives of this study were to: (1) evaluate the effects of FGD by-products on soil physical quality, (2) determine the influence of mining and reclamation activities on soil structural and mechanical properties, and (3) estimate the change in SOC pool following mined soil reclamation.

METHODS AND MATERIAL

Sites Description And Reclamation Options Field studies were conducted at a surface-mined site located in Franklin Township, Tuscarawas County, Ohio ($40^0$33'N and $81^0$31'W). Prior to reclamation the study area consisted of approximately 10 ha of exposed, highly erodible underclay; mine spoil and coal refuse were located on periphery. The spoil and underclay were extremely acidic, and pH ranged from 2.4 to 3.9. The soil at the reclamation site was classified as the Bethesda soil series (loamy-skeletal, mixed, acid, mesic Typic Udorthent) (Waters and Roth, 1986). The average annual precipitation for Tuscarawas County, Ohio, is 965 mm and average annual summer (June-August) air temperature is 21^0C. Six soil samples were obtained from each of the three land uses or treatments: (1) undisturbed soil (unmined; UMS), (2) reclaimed mined soil (RMS), and (3) spoil (SP) in May 2002. The UMS was under forage grass cover for over 25 years, whereas RMS sites were seeded to a grass-legume sward consisting of orchard grass (*Dactylis glomerata*), timothy (*Phleum pratense*), annual ryegrass (*Lolium multiflorum*), ladino clover (*Trifolium repense* Ladino), birdsfoot trefoil (*Lotus sp.*) and winter wheat (*Agropyron sp.*).

Three treatments applied to the RMS plots were: (1) flue gas desulfurization (FGD) wastes (280 $Mgha^{-1}$); (2) FGD + yard waste compost (FGDC, 280 $Mgha^{-1}$ + 112 $Mgha^{-1}$); and (3) soil +lime (SL, conventional method; 20 cm of borrowed soil + 45 $Mgha^{-1}$ of agricultural limestone was placed over 112 $Mgha^{-1}$ of limestone incorporated into graded spoil). The FGD and FGDC treatments were incorporated to 20 cm depth into graded spoil by a chisel plow (Dick et al., 1998). Four additional plots were selected for SP and UMS treatment in the year 2002. The plots under SP treatment were located on the northeast edge of the RMS, whereas those under UMS treatment at 40^0 33.35 'N and 81^0 34.35' W. The plots under SP treatment were flat whereas those under UMS and RMS were gently sloping (< 3%).

Soil sampling

Bulk and core soil samples were obtained in June 2002 for the determination of soil physical and chemical properties, and SOC ans SN pools. Soil samples were obtained in triplicate from each of the five treatments for 0 to 10 cm depth. Additional bulk soil samples for 10 to 20 cm depth were also obtained for each location.

Soil Properties Measured

1.Bulk Density (Core Method) , Soil Water Characteristic Curve (Tension table and Pressure plate apparatus), Water Stable Aggregation (Wet-sieving), mean weight diameter of aggregates, Particle Size Distribution (Hydrometer method),

2. Soil organic carbon and Soil nitrogen pools,
3. Infiltration rate at 5 min (i_5), infiltration rate at 2.5 h (i_c) and total infiltration (I) , Soil water sorptivity,
4. Soil pH and Electrical Conductivity

DISCUSSION

The soil ρ_b was the lowest for FGDC treatment probably because of the addition of organic amendments. The WSA was highest in the UMS treatment for both depths and agrees with the high SOC and I. Reclamation treatments enhanced soil structure, water retention and transmission parameters, and soil reclamation with FGD by-products improved soil structure. Soil development was evident by high WSA, MWD, I and pH, and low ρ_b. High pH supports above ground biomass, root development and increases C sequestration. FGDC seemed to be an effective reclamation material especially when topsoil is unavailable or costs of transport are high. We did not observe any dramatic increases in EC for FGD and FGDC treatments. Still, leaching of trace elements with FGD application needs to be further studied. The SOC concentration in RMS was higher than in SP but lower than UMS, which indicates the potential of C sequestration through conversion to a restorative land use and improved management practices.

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Table 1. Effect of reclamation treatments on soil bulk density (ρ_b) and sand and clay concentration. The mean separation is done by analysis of variance with one factor design

Treatment	ρ_b	Sand		Clay	
	0-10cm	0-10cm	10-20cm	0-10cm	10-20cm
	Mg m^{-3}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}
FGD	0.94b	443.6b	454.8ab	70.8b	67.5c
FGDC	0.88b	511.3a	489.2a	116.3b	81.7c
SL	1.34a	291.1d	322.3c	369.9a	405.3a
SP	1.48a	369.2c	416.1b	391.7a	337.2b
UMS	1.28a	130.1e	125.7d	360.4a	361.6ab
LSD (0.05)					
	0.23	50.0	45.4	69.5	56.5

FGD- flue gas desulfurization, FGDC- FGD + compost, SL- soil + lime, SP- spoil, UMS- unmined soil, LSD- least significant difference

Table 2. Effect of different land use and reclamation treatments on soil organic carbon (SOC) and nitrogen (TSN) pools

Treatment	SOC		TSN	
	0-10cm	10-20cm	0-10cm	10-20cm
	Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}
FGD	21.9d	21.2c	1.31c	1.11b
FGDC	27.4c	29.5b	1.70bc	1.19b
SL	32.9b	31.9ab	1.87b	1.37b
SP	11.6e	13.4d	1.40bc	0.94b
UMS	40.0a	37.2a	3.4a	2.68a
LSD (0.05)				
	3.33	6.15	0.53	0.46

Table 3. Effect of different land use and reclamation treatments on water stable aggregation (WSA) and mean weight diameter (MWD)

Treatment	WSA		MWD	
	0-10cm	10-20cm	0-10cm	10-20cm
	g kg^{-1}	g kg^{-1}	mm	mm
FGD	161.7b	134.3b	0.90b	0.36bc
FGDC	220.8b	253.5b	0.97b	0.88b
SL	555.8a	513.4a	1.40a	2.66a
SP	150.4b	142.3b	0.69c	0.13c
UMS	609.2a	630.5a	0.93b	2.29a
LSD (0.05)				
	123.91	130.94	0.20	0.62

Table 4. Effect of different land use and reclamation treatments effective porosity (f_e), available water content (AWC) of soil and saturated hydraulic conductivity (K_s)

Treatment	f_e $cm^3\,cm^{-3}$	AWC cm	K_s cm h^{-1}
FGD	0.14ab	1.33b	20.17ab
FGDC	0.16a	1.80ab	26.17a
SL	0.11b	1.69ab	9.28ab
SP	0.13ab	1.36b	0.70b
UMS	0.11ab	1.94a	33.40a
LSD (0.05)			
	0.05*	0.51	25.0

Table 5. Effect of different land use and reclamation treatments on water transmission properties of soil from ponded infiltration tests

Treatment	i_5 cm h^{-1}	i_c cm h^{-1}	I cm	S cm $h^{-0.5}$
FGD	33.0ab	10.4a	34.80ab	31.43ab
FGDC	31.0b	13.2a	39.75a	19.86bc
SL	38.4ab	8.9ab	30.60ab	31.32abc
SP	9.1b	1.4b	6.42b	8.50c
UMS	72.0a	13.6a	52.88a	47.88a
LSD (0.05)				
	39.41	8.61	29.53	22.93

Table 6. Effect of different land use and reclamation treatments on electrical conductivity (EC) and pH of soil

Treatment	EC		pH	
	0-10cm dS/m	10-20cm dS/m	0-10cm	10-20cm
FGD	0.11bc	0.09	7.5a	6.9a
FGDC	0.03c	0.18	6.5b	6.2a
SL	0.47a	0.16	7.2ab	6.5a
SP	0.03c	0.03	3.4c	3.3b
UMS	0.18b	0.11	6.6b	6.9a
LSD (0.05)				
	0.11	NS	0.75	1.03